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# Project-organized learning and the development of competences in Engineering Education for Sustainable Development

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## Abstract

The integration of Education for Sustainable Development (ESD) principles has been claimed for all levels and areas of formal education. The integration of new kinds of competences, skills and knowledge into the engineering curricula aims to prepare future engineers to face the challenges posed by the complex and economically driven society and develop innovative technologies to solve and prevent sustainable problems. In this perspective, ESD experts have stressed sustainability aspects as well as cross-disciplinary competences, such as inter-disciplinarity, adaptability, problem solving, critical thinking, systems thinking, etc. It is argued that Problem-Based Learning (PBL) provides a suitable framework for developing the competences mentioned, but there is a lack of studies that investigate the room which PBL practice leaves for ESD. In this study, we aim to investigate the staff's perception of what engineering students do; which aspects they touch upon, and which type of knowledge they gain in a PBL environment and how this reflects the ESD principles. The study includes two engineering programs in the PBL environment at Aalborg University, Denmark. The results show distinct strategies for integrating ESD and different interpretations of PBL, which, at the same time, can be questioned and hold the potential for cross-fertilization and development. However, the results also show a strong emphasis on problem solving as well as systemic and holistic perspectives on the integration of ESD. This indicates that, although a PBL framework makes perfect room for integrating ESD, a coordinated and comprehensive strategy must be implemented to make use of the provided space.

**Keywords**: Engineering education for sustainable development; competences, problem-based and project-organized learning.

## Introduction

Several engineering education reports, accords, and qualification frameworks for accreditation call for a change in engineering programs to face the so-called grand challenges of our time; thus, the increased complexity of technological as well as social systems and a call for sustainable development. Washington Accord (2009, p. 1) states that engineering activity "*must be carried out with responsibly and ethically, use available resources efficiently, be economic, safeguard health and safety, be environmentally sound and sustainable and generally manage risks throughout the entire lifecycle of a system*". To fulfill this aim, knowledge, skills, and competences are required to move beyond the traditional applications related to science, technology, engineering and math (STEM). Recent qualification frameworks as well as educational research within the field of Education for Sustainable Development (ESD) stress this.

ABET (2010, p. 3) presents eleven students' outcomes in *2011-2012 Criteria for Accrediting Engineering Programs*, like for example, the "*ability to communicate effectively"*; *"an ability to design a system, environmental, social, political, ethical, health and safety, manufacturability, and sustainability*"; "*knowledge of contemporary issues*". In the *Framework Standards for the Accreditation of engineering programmes,* the ENAEE (2008, p. 7) points to transferable skills as a requirement and defines these as "*skills necessary for the practice of engineering, and which are applicable more widely*". Also in other clusters, such as engineering analysis, design or practice, the learning outcomes formulated address the awareness and importance of "*social, health and safety, environmental and commercial*" considerations and constraints of engineering practice and knowledge (EUR-ACE, 2008, p. 5). *The Global Engineer* (Bourn & Neal, 2008), furthermore, defines a new kind of engineer as the title point; an engineer capable of "*being*" an entrepreneur, academic and researcher, and also environmentally and socially responsible.

One of the challenges faced by engineering education is to make its curricula more innovative, with the integration of competences and skills that prepare engineers for a working environment, but also new economic and social demands. The new ways of educating engineers for 21st century professions go beyond technical and scientific knowledge; by also involving competences and skills like, for example, self-directed learning, cooperation, communication, critical thinking, and problem solving. Some of these competences require a learning environment in which, rather than the transmission of principles and generalizations of core disciplines, a learning process is created in which the student is actively involved and is responsible for his/her knowledge construction. In sum, an inductive learning process, rather than a deductive, is created in which students can apply knowledge into real contexts and generate knowledge from the practical/ experienced situation by reflection, as represented by Kolb's learning cycle (Bourn & Neal, 2008; Grasso & Burkins, 2010).

As sustainable development (SD) is described in the qualification frameworks for engineering education. The request for competences moving beyond subject matters is echoed in the principles for Education for Sustainable Development (ESD) in general (see for example Gough & Scott, 2007) as well as in relation to engineering education (Engineering Education for Sustainable Development, 2004; Ferrer-Balas & Mulder, 2005; Royal Academy for Engineering, 2005; Bell, 2011). Sterling (1996) characterizes education for sustainability as contextual; innovative and constructive; focused and infusive; holistic and human in scale; integrative; process-oriented and empowering; critical; balancing; systemic and connective; ethical; purposive; inclusive and lifelong. Brundiers & Redman (2010) argue for three clusters of competences in sustainable development in terms of knowledge:

- strategic knowledge (systemic, anticipatory, normative and action-oriented competences, including the content and methodology of each of these competences);

- practical knowledge (competences linking knowledge and action like hands-on experience, in which adequate knowledge is mobilized and integrated in practice);
- and collaborative knowledge (competences of team work, communication).

Drawing from case examples of engineering practice related to sustainable development, The Royal Academy for Engineering (2005, p. 25) points out twelve principles of ESD, which include being innovative and creative, seek balanced solutions; and adopt a holistic, 'cradle-to-grave' approach. The pressure of sustainable problems, such as climate change, poverty, resource scarcity, increased energy demand, and population growth, calls for new perspectives on engineering practice, including the abilities to:

1. foresee adverse and unsustainable consequences of the development of new technologies and take these consequences into consideration as early as possible in the design process.
2. provide sustainable solutions by substituting less sustainable alternatives or redesigning existing solutions for sustainability;
3. discuss and make trade-offs between possible conflicting sustainability impacts
4. document the impact of a solution taking the whole lifecycle as well as economic, social and environmental sustainability into consideration.

Sustainability science has provided engineers with a lot of tools to cope with this situation, conceptualized as eco-design, life cycle assessment, environmental management systems, occupational health and safety systems, etc. (see for example Kørnøv *et al*, 2007). Likewise, the research field of science and technology studies (STS) has provided a range of conceptions to bring attention to the social context of science and technology, like different types of technology assessment and views on adapting technology to society (see for example Bell, 2011)

The question is, however, how the education institutions can educate engineers who are capable of meeting the new requirements for the engineer of the 21st century, without compromising the more traditional STEM learning objectives. This, first of all, calls for attention to the process of selecting curricula context – in other words, what should engineers know about sustainability to be able to contribute to sustainable solutions? Furthermore, and as noted by Sterling (1996; 2004b), this calls for a paradigm shift, and thereby, institution wide pedagogical models, curricula as well as pedagogical practices have to be renegotiated.

*Pedagogical principles of ESD*

The pedagogical principles stressed by researchers within the field of ESD call for:

- real life experiences (Corcoran & Wals, 2004; Sterling, 2004a; 2004b; Steiner & Law, 2006; Steiner & Posch, 2006),
- problem solving (Sterling, 1996; Steiner & Law, 2006; Steiner & Posch, 2006)
- action orientation (Sterling, 2004b; Cocoran & Wals, 2004; UNESCO, 2009),
- critical reflections (Sterling, 2004a; McKeown, 2002, UNESCO, 2009);
- creative inquiry (Sterling, 2004a, Wagner & Dobrowolski, 2000),
- future thinking (McKeown, 2002; UNESCO, 2009; Lozano & Peattie, 2009);
- systemic thinking (Wagner & Dobrowolski, 2000;; McKeown, 2002; UNESCO, 2009)
- contextual (Sterling, 1996; Corcoran &Wals, 2004)
- flexibility and adaptability (Sterling 1996; Royal Academy of Engineering, 2005)
- collaborative and communicative learning (Sterling, 2004a; Corcoran & Wals, 2004; McKeown, 2002; UNESCO, 2009)

- democratic and participative learning (Sterling, 1996; 2004a; McKeown, 2002; UNESCO, 2009)
- decision-making (Royal Academy of Engineering, 2005; Perdan 2004; Bourn & Neal, 2008)
- empowerment of learners (Wagner & Dobrowski, 2000)

These principles are strikingly close to the principles of problem-based learning presented by (Kolmos et al., 2009) stressing the real life and action-oriented, contextual, collaborative, and participant-directed approach to learning.

In the Problem-Based Learning (PBL) approach, the learning process starts with a formulation of a problem, and the problem solving process leads to the development of thorough knowledge, skills and competences. In opposition to standardized problems, which aim to illustrate a block of knowledge learned and present solutions which are previously known by the students, the problem solving process is, as the solution, unknown. Examples of PBL practice are found at different levels of education (compulsory to higher education, from learning strategy to curriculum development), and in different areas (form medicine to engineering); however, all the varieties and forms are characterized by constructivism (students are active and responsible in their learning process) and relations between theoretical knowledge and professional practice are stressed (Biggs, 2003; Savin-Baden & Howell, 2004; Kolmos *et al*, 2009).

Different combinations of PBL principles, as for example the type of problem (e.g., from well-structured to less structured); the type of disciplinary knowledge (e.g., from disciplinary factual and declarative knowledge to interdisciplinary procedural knowledge); the role of students (more or less autonomous); the role of staff (more or less directive); the progression (different phases and time required to solve the problem) and the assessment systems (more or less group-based), lead to different PBL models. The different models reflect different levels of complexity; different sites in which the learning process takes place, and different levels of cognitive abilities and competences (Savin-Baden & Howell, 2004; Kolmos *et al*, 2009; Jonassen, 2011). For example, in case-organized PBL (common in medical education), problems tend to be more narrow and with detailed information, while in project-organized learning, problems are often poorly structured and from real situations. In project-organized PBL, students do not only mobilize and learn the knowledge required, but the nature of this knowledge is in itself different; it is contextual, strategic and functional (Biggs, 2003) (Figure 1 PBL process and main activities and competences).

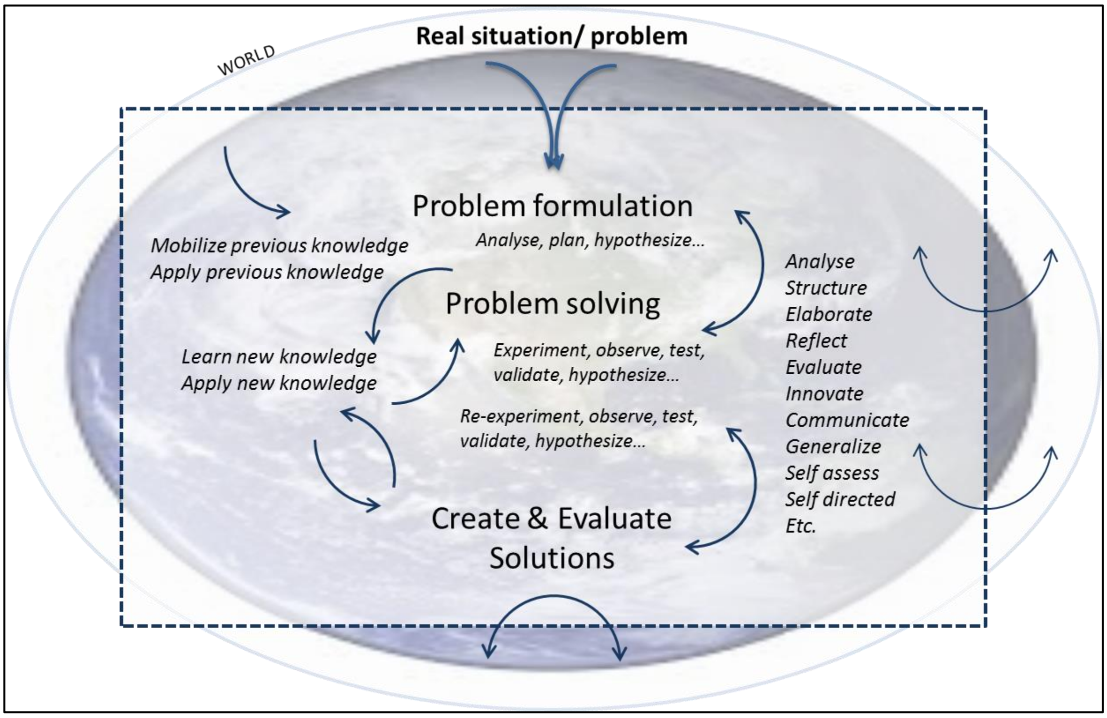


**Figure 1** PBL process and main activities and competences

Figure 1 illustrates the PBL process where real-life problems are analyzed, formulated and solved with the integration of previous as well as new knowledge and aligned with a professional, social, and/or economic context. The process represented in the figure is simplified, but underlines the fundamental principles of PBL contextualizing learning in social systems. These systems acquire an increasing level of complexity, as the boundaries of the problem field expand; e.g., if the problems formulated cross boundaries of disciplines, integrate several professional areas, etc. In sum, PBL is a dynamic system with multiple variables and interconnections, reflecting the possibilities and complexity of real professional life, where students act, decide and learn how to navigate to achieve the goals they have formulated.

**Research question and methodology**

In this paper, we have argued that PBL appears as a suitable learning approach to educating engineers for sustainable development. It does not only create the learning environment for competences, skills and knowledge of sustainable development, like critical thinking, interdisciplinary and participatory learning, problem solving, creativity and innovation, collaboration, communication, etc. It also provides an environment in which concrete applications of competences to ESD, fundamental skills for practice, and discipline/academic content converge and create the context for learning (Perin, 2011). Thereby, with reference to Sterling (2004b), ESD can move beyond the characterization as an education “about” sustainability to an education “for” a sustainability approach – and even if the problem is directly related to sustainability and calls for the student’s active participation and impact, this pedagogical frame holds the potentials for education “as” sustainability development.

In this study, we will compare different programs from the same PBL environment to investigate:

*In which way is the PBL environment reflected in the ESD?*

This research question will be addressed by means of a qualitative study conducted at Aalborg University, Denmark, involving two engineering Master’s programs - Structure & Civil Engineering

(SCE), and Urban Planning & Management (UPM). At Aalborg University, all the engineering programs, from Bachelor to Master's level, are problem-oriented. These programs are chosen for two reasons. First of all, a content analysis of the curricula showed the presence of sustainability aspects, and secondly, the two programs complement each other by their related and yet different perspectives on urban development.

*Instrument for data collection and analysis*

The instruments for data collection and analysis are based on previous literature reviews, resulting in a set of checklists and interview guides with follow-up questions (Table 1).

**Table 1** Data collection and data analysis

| **Data collection** | | **Data Analysis** | |
|---|---|---|---|
| *Techniques* | *Instruments* | *Techniques* | *Instruments* |
| Questionnaire | Checklists | Content analysis | Content analysis grid |
| Semi-structured interview | Interview guide | | |

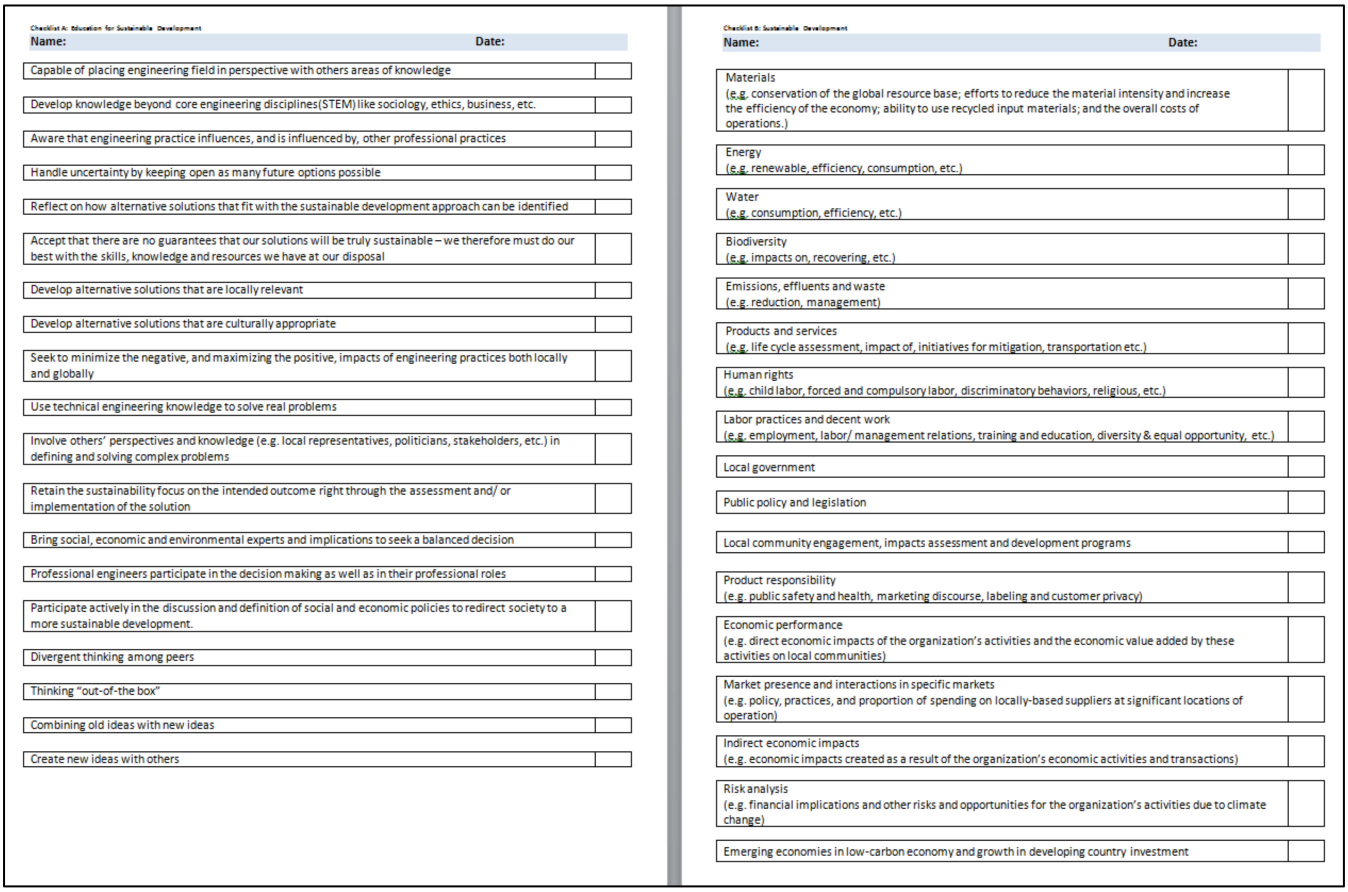
For the collection and analysis of data, criteria and indicators of education for sustainable development, sustainability, type of knowledge, disciplinarity and critical thinking are defined as the results of a literature review and meta-analysis (Table 2).

**Table 2** Criteria for checklist for collection and data analysis

| **Criteria for Checklist** | |
|---|---|
| **Checklists** | **Categories** |
| **A.** Principles of ESD | Systemic & holistic thinking<br>Flexibility and adaptability<br>Contextual<br>Problem Solvers<br>Participatory learning & decision-making<br>Creativity and innovation |
| **B.** Sustainability aspects | Environment<br>Society<br>Labor practices and decent work<br>Human Rights<br>Product responsibility<br>Economy |
| **C.** Knowledge | Factual & Conceptual;<br>Procedural;<br>Metacognitive;<br>Personal & evolutionary |
| **D.** Disciplinarity | Disciplinary;<br>Cross/ multidisciplinary;<br>Interdisciplinary;<br>Transdisciplinary |

The checklists, in total of 4, are concerned with the different elements of ESD and PBL. For example, the indicators in checklist A are related with different basic principles of education for sustainable development, while checklist B is concerned with different indicators of sustainable development (Figure 2). Checklists C and D address type of knowledge and disciplinarity, respectively.

The checklists are constructed by formulating indicators related to the theme by subtracting different abilities, subjects or environments from the literature review and ask the staff to what the students are exposed during their Master's education. Members of the study board were asked to point out the main indicators that are addressed in the program curriculum. Lecturers were asked to define what students achieve/ do in their courses, and facilitators were asked to point out what students manifest along the project work. After the completion of each checklist, some follow-up questions were posed, pushing the participants to explain, in some cases, how students manifest the indicators; which type of students and why they do so, but also giving some insights into barriers and drivers.


Checklist A: Education for Sustainable Development
Name: Date:

| | |
|---|---|
| Capable of placing engineering field in perspective with others areas of knowledge | |
| Develop knowledge beyond core engineering disciplines(STEM) like sociology, ethics, business, etc. | |
| Aware that engineering practice influences, and is influenced by, other professional practices | |
| Handle uncertainty by keeping open as many future options possible | |
| Reflect on how alternative solutions that fit with the sustainable development approach can be identified | |
| Accept that there are no guarantees that our solutions will be truly sustainable – we therefore must do our best with the skills, knowledge and resources we have at our disposal | |
| Develop alternative solutions that are locally relevant | |
| Develop alternative solutions that are culturally appropriate | |
| Seek to minimize the negative, and maximizing the positive, impacts of engineering practices both locally and globally | |
| Use technical engineering knowledge to solve real problems | |
| Involve others' perspectives and knowledge (e.g. local representatives, politicians, stakeholders, etc.) in defining and solving complex problems | |
| Retain the sustainability focus on the intended outcome right through the assessment and/ or implementation of the solution | |
| Bring social, economic and environmental experts and implications to seek a balanced decision | |
| Professional engineers participate in the decision making as well as in their professional roles | |
| Participate actively in the discussion and definition of social and economic policies to redirect society to a more sustainable development. | |
| Divergent thinking among peers | |
| Thinking "out-of-the box" | |
| Combining old ideas with new ideas | |
| Create new ideas with others | |

Checklist B: Sustainable Development
Name: Date:

| | |
|---|---|
| Materials (e.g. conservation of the global resource base; efforts to reduce the material intensity and increase the efficiency of the economy; ability to use recycled input materials; and the overall costs of operations.) | |
| Energy (e.g. renewable, efficiency, consumption, etc.) | |
| Water (e.g. consumption, efficiency, etc.) | |
| Biodiversity (e.g. impacts on, recovering, etc.) | |
| Emissions, effluents and waste (e.g. reduction, management) | |
| Products and services (e.g. life cycle assessment, impact of, initiatives for mitigation, transportation etc.) | |
| Human rights (e.g. child labor, forced and compulsory labor, discriminatory behaviors, religious, etc.) | |
| Labor practices and decent work (e.g. employment, labor/ management relations, training and education, diversity & equal opportunity, etc.) | |
| Local government | |
| Public policy and legislation | |
| Local community engagement, impacts assessment and development programs | |
| Product responsibility (e.g. public safety and health, marketing discourse, labeling and customer privacy) | |
| Economic performance (e.g. direct economic impacts of the organization's activities and the economic value added by these activities on local communities) | |
| Market presence and interactions in specific markets (e.g. policy, practices, and proportion of spending on locally-based suppliers at significant locations of operation) | |
| Indirect economic impacts (e.g. economic impacts created as a result of the organization's economic activities and transactions) | |
| Risk analysis (e.g. financial implications and other risks and opportunities for the organization's activities due to climate change) | |
| Emerging economies in low-carbon economy and growth in developing country investment | |

**Figure 2** Examples of checklists (checklist A - principles of education for sustainable development and checklist B - sustainable development indicators)

*Data collection*

After choosing the programs, different members of faculty staff were contacted and the data was collected between May 2012 and January 2013 (the second semester of UPM and third semester of SCE) through questionnaires/checklists and semi-structured interviews. A total of fourteen, out of twenty-eight, staff members participated in the study, seven from each program (Table 3).

**Table 3** Participants in the study

| **Role** | **UPM (2nd semester)** | | **SCEng. (3rd semester)** | |
|---|---|---|---|---|
| | *Aimed* | *Achieved* | *Aimed* | *Achieved* |
| Study board(*) | 6 | 1 | 6 | 2 |

| | | | | |
|---|---|---|---|---|
| Lecturers | 3 | 1 | 5 | 4 |
| Facilitators | 4 | 4 | 4 | 2 |

[(*)] Composed by academic and administrative staff and students' representatives. The target group is the academic staff.

In UPM, a total of thirteen people were invited for interviews, while in SCE, it was a total of fifteen people. All interviews and comments to the checklists were recorded.

The two programs belong under two different study boards, from different schools within the Faculty of Engineering and Science. However, the structures of the study boards are similar, as they involve academic members, the representative and responsible for the curriculum of the different programs, a chair as well as student representatives. In both programs, the chair and the representative responsible for the curriculum were invited to participate in the study.

*Data analysis*

The data collected was organized in grids for the content analysis, both for the checklists and for the follow-up interviews (Table 1). Figure 3 illustrates an example of a grid of a content analysis, according to which results are organized as well.

In the example given in the figure, and common to all grids of the content analysis, the first column shows the categories of analysis, that is, the different types of disciplinarity considered: disciplinary, multidisciplinary, cross-disciplinary, interdisciplinary, transdisciplinary. The second column presents the indicators related to the different types of disciplinarity, and the following two columns show the results from each of the engineering programs.

| | | *Structure & Civil Engineering* | | | | | | | *Urban Planning and Management* | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | C.F. | R.J. | B.N. | J.A | J.S. | H.T. | J.N. | C.L. | S.L | D.G | E.L | K.O | P.D |
| | | *Study Board* | | *Lecturers* | | | *Supervisors* | | *Study board* | *Lecturers* | | *Supervisors* | | |
| **D.1.Disciplinary** | D.1.1. Knowledge within your engineering subfield<br>D.1.2. Study of courses related with engineering (e.g. mathematics, physics, etc.) | | | | | | | | | | | | | |
| **D.2.Multidisciplinary** | D.2.1. Have knowledge from different disciplines (e.g. history)<br>D.2.2. Aware of others disciplines works<br>D.2.3. Study of others subjects like finance, humanities, etc. | | | | | | | | | | | | | |
| **D.3.Cross-Disciplinary** | D.3.1. Topic of investigation is from other area of study<br>D.3.2. Use of techniques and tools that is commonly used by experts of other disciplines (e.g. using interview as method in civil engineering project) | | | | | | | | | | | | | |
| **D.4.Interdisciplinary** | D.4.1. Combines methods and approaches from different disciplines<br>D.4.2. Two or more disciplines which interact and combine their expertise to jointly address an area of common concern. | | | | | | | | | | | | | |
| **D.5.Transdisciplinary** | D.5.1. Formulate new theories and methodologies from different disciplines<br>D.5.2. Two disciplines merge to create a new one (e.g. nanotechnology, product design and technology…) | | | | | | | | | | | | | |

**Figure 3** Example of grid of content analysis (for data analysis of checklist D – disciplinarity)

The interviews were transcribed and coded with the help of software N-vivo 9. In this investigation, the scripts are taken as our point of departure to gain an overview of the ESD elements to which the students are exposed. However, the coded transcripts were used for further elaboration and discussion of the results from the grids of the checklists.

## Results

The grids of the content analysis of each checklist and the interview are included as appendixes (Appendixes 1 to 5). In the following, the main results from the content analysis of each checklist are emphasized. First question is to point out a maximum of 5 indicators of ESD that the students manifest along the learning process, having as reference the semester they are in. Some of the participants pointed out five indicators; others insisted to mark more or fewer. The most relevant quotations from the interviews are added to the results of the checklists for further elaboration.

*Structure and Civil Engineering (SCE)*

The different checklists present actions, themes and approaches which already exist in the programs, independently of the aim of integrating sustainable development into the education.

In Table **4**, the main results from each checklist are presented, according to the categories. The categories are ordered according to the number of indicators chosen.

**Table 4** Main results

| Checklists | Category | Indicators |
|---|---|---|
| **A -** Education for sustainable development principles | Problem solvers (A.4) | Use technical engineering knowledge to solve real problems (A.4.1.) |
| | Creativity and Innovation (A.6) | Combining old ideas with new ideas (A.6.3.) |
| | Systemic and holistic (A.1) | Awareness of the fact that engineering practice influences, and is influenced by, other professional practices (A.1.3) |
| **B -** Sustainable development indicators | Economic (B.3) | Risk analysis (B.3.4) |
| | Environmental (B.1) | Materials (B.1.1) |
| **C** - Type of knowledge | Factual and conceptual | Knowledge of theories, models, and structures (C.1.3.) |
| | | Knowledge of facts, elements and/ or terminology (C.1.1.) |
| | Procedural | Knowledge of subject-specific techniques and methods (C.2.2.) |
| **D -** Disciplinarity | Disciplinary | Study of courses related with engineering (e.g., mathematics, physics, etc.) (D.1.2.) |
| | | Knowledge within your engineering subfield (D.1.1.) |
| | Multidisciplinary | Awareness of how other disciplines work (D.2.2.) |

In terms of *ESD abilities*, staff within SCE indicated a strong relation to PBL as seven out of eight respondents chose the indicator “Use technical engineering knowledge to solve real problems”. Secondly, five out of seven signaled an emphasis on creativity and innovation, although in a rather traditional sense, by stressing the combination of old ideas with new. Third, the systemic and holistic perspective was stressed, emphasizing that students are aware that an engineering practice influences, and is influenced by, other practices.

In regard to *SD indicators,* the participants from the SCE Master’s program are unanimous in pointing to the economic pillar of sustainability by stressing risk analysis. Furthermore, there is a high degree of attention to the environmental impacts related to materials, energy and products, and services. Furthermore, with the exception of environmental impacts related to water, all other environmental impacts seem to be emphasized by one or more of the lecturers/facilitators. The social aspects have rather low priorities in the program, except for a very limited emphasis on public policy and regulation as well as product responsibility.

The *type of knowledge* emphasized in the program is factual and cognitive as well as procedural knowledge. As an example of the factual and cognitive abilities to use technical engineering, the knowledge about how to solve real problems is stressed. Procedural knowledge is linked with the learning environment, the project-organized learning, in which the learning process is driven by a problem-solving process. In this way, the conception of knowledge is very much aligned with the project-oriented approach. But at the same time, there is a risk of neglecting metacognitive knowledge related with critical thinking, reflection, and higher cognitive tasks.

Regarding *disciplinarity*, the SCE approach seems rather traditional in its focus on socializing students in their specific engineering discipline; however, it is also stressed that students have to be aware of how other disciplines work and be able to combine methods and approaches from different disciplines. However, there is no doubt that this discipline has an identity which is strongly related to STEM.

*Urban Planning & Management (UPM)*
The UPM program is a specialization of the program of Urban, Energy and Environment Planning and shares one course per semester with two other specializations (Environmental Management and Sustainability Science and Sustainable Energy Planning and Management). The two other programs have sustainability science as a core; however, this is not the case of UPM.

Table 5 presents the main results from the respondents from the program UPM. The indicators, and their categories, are ordered according to the number of times that they were pointed out by the participants.

**Table 5** Main results

| Checklists | Main results | |
|---|---|---|
| **A -** Education for sustainable development principles | Problem solvers (A.4) | Involve others' perspectives and knowledge (e.g., local representatives, politicians, stakeholders, etc.) in defining and solving complex problems (A.4.2.) |
| | Systemic and holistic thinking (A.1) | Awareness of the fact that engineering practice influences, and is influenced by, other professional practices (A.1.3.) |
| | Participatory learning and decision-making (A.5) | Participate actively in the discussion and definition of social and economic policies to redirect society to a more sustainable development (A.5.3.) |
| | Creativity and Innovation (A.6) | Thinking "out of the box" (A.6.2.) |
| **B -** Sustainable development indicators | Social (B.2) | Local government |
| | | Public policy and legislation |
| | | Local community engagement, impact assessment and development programs |
| **C -** Type of knowledge | Factual and cognitive (C.1) | Knowledge of theories, models, and structures (C.1.3.) |
| | Metacognitive (C.3) | Awareness of the limits of one's knowledge (self-knowledge) (C.3.3.) |
| | Evolutionary, or world (C.4) | Knowledge about the values and attitudes (importance and challenges of other moral |

| | | |
|---|---|---|
| | | perspectives on issues) of others (actors, disciplines, communities, systems) (e.g., other discipline members' beliefs of what is right and wrong, values and behavior, etc.) (C.4.3.) |
| **D** – Disciplinarity | Multidisciplinary (D.2) | Have knowledge from different disciplines (e.g., history) (D.2.1.) |
| | Interdisciplinary (D. 4) | Combine methods and approaches from different disciplines (D.4.1.) |
| | | Two or more disciplines which interact and combine their expertise to jointly address an area of common concern. (D.4.2.) |

In terms of *ESD abilities*, staff within UPM indicated their relation to PBL, as four out of six respondents stressed the indicator "Involve others' perspectives and knowledge in defining and solving complex problems" in the category of systemic and holistic abilities. The collaborative nature of PBL is also reflected in the emphasis on participation and decision-making, stressing the ability to participate actively in discussing and defining social and economic policies to redirect society to a more sustainable development. Furthermore, creativity and innovation are stressed as the ability to think out of the box.

In regard to *SD indicators*, the participants from UPM stress the social pillar of sustainability, in relation to local government, public policy and legislation, and local community engagement. The social factors seem to be closely related to the program, as only six of the possible 30 marks fall outside this category.  The limited marks on environmental impacts highlight materials, biodiversity and emissions, whereas the few marks in the economic field are related to risk analysis and low-carbon economies.

The *type of knowledge* emphasized in UPM is factual and cognitive, metacognitive as well as evolutionary. As an example of factual and cognitive abilities, the knowledge of theories, models and structures is stressed. The relation to PBL is, however, more to be found in the meta-cognitive area, in which self-knowledge and reflection are stressed. Furthermore, the evolutionary approach is stressed by the emphasis on the knowledge of the values and attitudes of others (actors, disciplines, communities, systems), which, by reading the curriculum, can be connected to a strong relation to the domain of science and technology studies (STS).

Regarding *disciplinarity*, the UPM discipline seems almost to be defined by multi-, cross- and interdisciplinarity. In the multi-disciplinary field, four out of six respondents stress the need to have knowledge from different disciplines, and three stress the awareness of how other disciplines work. Furthermore, two even stress the need to study other subjects like finance and humanities. In the multidisciplinary field, three respondents likewise mark the use of techniques and tools from other disciplines and the need to consider topics of investigation from other areas of studies. In the field of inter-disciplinarity, students experience that two or more disciplines interact and combine their expertise to jointly address an area of common concern.

**Discussion**

In the staff's perspectives, PBL is reflected in different ways considering the ESD abilities developed by the students; which sustainability aspects they touch upon; which type of knowledge is emphasized, and the degree to which the students reach inter-disciplinarity in their studies. However, the way in which PBL is reflected is rather different in the different programs. This is not at all problematic, as the PBL framework, like the integration of sustainability, comes and should come in difference shades, depending on the context of the discipline. The question is, however, how the PBL principles are adapted to the different disciplines. In the following, we present a thematic discussion taking our point of departure in this question.

*1. Strong systematic and holistic perspectives – but still on safe "engineering" ground*

In a PBL environment as well as in an ESD perspective, the focus on real-life problems most often calls for a systemic approach moving beyond STEM. The systemic and holistic perspective was stressed in both programs, emphasizing the awareness of the fact that engineering practice influences, and is influenced by, other practices. Some of the respondents emphasizing a systemic and holistic approach even underline this by pointing towards contextual factors which enable the students to develop alternative solutions that are locally relevant and culturally appropriate.

The study board representative from SCE also indicated that the students should be capable of placing the engineering field in perspective with other areas of knowledge. However, that was not on the top 5 priority list of the practitioners – not even for the respondent providing more marks than five. The systemic and holistic approach is there, but it receives marginal attention compared to the technical considerations. The following quote from a member of staff from Civil Engineering illustrates this point of view (Staff interview a, 2013):

*"I would like to see it in the project. When they are doing a project they have to assess what the impact is of doing this …the social, environmental impacts and so on … it is difficult (ed.: making it count in an assessment) because we are very much fixed on the technical aspects, so realistically your grade will not rely very much on that you can tick this off, that will be the technical parts – are the calculations correct, are the drawings correct and so on. So it will be very much in the background… not much work of the students is going into this for the projects I know. They are very quick into the technical stuff…but we are to blame because that is what we assess."*

The same was actually the case of the study board of Urban Planning and Development. The study board representatives marked the development of knowledge beyond core STEM disciplines like sociology, ethics and business, etc. But only one of the practitioners had the same priority.

Some of the explanation might be found in the curricula, as the contextual knowledge is provided by introducing science and technology studies in the first year of the Bachelor's program. However, another explanation could be the distinction between *being aware of* and *developing knowledge* in moving beyond the STEM principles. In any case, the discrepancy between the priorities put forward by the study board and by the practitioners, respectively, could lead to the conclusion that implementing a systemic and holistic view is easier said than done.

*2. Different disciplines – different sustainability pillars*

In regard to *SD indicators*, the participants from the SCE Master's program are unanimous in pointing to the economic pillar of sustainability related to risk analysis as well as environmental impacts related to materials. When we look into the social pillar of sustainability, none of the staff members from construction and civil engineering have marked the importance of human rights, labor practices, and decent work and local community engagement. On the contrary, the participants from UPM stress the social pillar of sustainability, in relation to local government, public policy and legislation, and local community engagement. But is this in fact logical?

Cities of the future require more space for construction, resources and energy, and will produce more waste, etc. It is necessary to educate engineers to have a sustainable perspective on future constructions and how they are planned. Thereby, a strong emphasis on environmental impacts seems reasonable. On the other hand, literature that relates civil engineering to activities with adverse impacts on the environment also stress that they provide the conditions for quality of life (Chau, 2007; UNESCO, 2009). As stated in the curriculum, the program also involves the "*design of main structural components for wind turbines and wave energy devices*" in order to "*understand and communicate basic design problems for wind turbines and wave energy waves*" as alternative energy sources beside fossil fuels (School of Engineering and Science, 2010, p. 16).

Furthermore, speaking of PBL, the students of UPM and SCE could in fact have the same point of departure in terms of real life problems related to for example creating a more sustainable living. This questions the actual openness of the curricula in terms of contextualization and freedom to choose appropriate solution strategies. As stated in the curricula of both programs, as part of the competence profile, the students must be able to:

"*select and apply appropriate methods for solving a given problem within civil engineering and judge the results regarding their accuracy and validity*" (…) "*initiate and implement discipline-specific as well as interdisciplinary cooperation and assume professional responsibility*" (School of Engineering and Science, 2010, p. 6)

"*analyze the effect that the implemented or proposed strategy or superior plan as well as one or two alternative strategies are expected to have on the further urban and transport infrastructure development*" (School of Architecture, Design and Planning, 2010, p. 9)

However, these formulations are very open, and this openness has, at the same time, the opportunity to embrace sustainability and ignore sustainability. In other words, the PBL nature of a curriculum does not in itself secure ESD. The following quote underlines this statement (Staff interview b, 2013):

*I mean a lot of these things are actually something that they should learn implicitly by doing projects and problem-based learning (PBL). But... I think one of the problems at the moment with the new curriculum is that we have not really, at least for a period of time, we have just told ourselves the students become very good by doing PBL, they become really good engineers, we know we get good feedback from industry and so on. But we have really not sat down and really specified the competences that they get from doing this, which means that when we do the curriculum, and just the curriculum, there is a tendency that these things that we didn't put on words can be somewhat neglected. We think it will stay there no matter what we do...*

*3. Different but distinct strategies for problem solving*

Both programs emphasize factual, conceptual and self-reflective knowledge, but when moving from this kind of knowledge to skills and competences, different strategies are aligned with PBL in different ways. The staff from SCE stresses procedural knowledge which is very much aligned with the project-oriented approach; whereas the UPM staff emphasizes the meta-cognitive and evolutionary approach. A staff member of UPM explains (Staff interview c, 2013):

*"You have the very technical pole, like the tradition I am coming from myself, having a lot of difficulties in reflecting on your own knowledge production. And at the other pole, it is the only thing you do, where I would like to go somewhere in between, saying that you should both have some*

*competences where you can be technical and you can solve things … but you should also be able to, and that is a huge lack in many engineering educations, reflect upon your own practice and your own knowledge production and be able to think about why do I do this at all. It should not be because of the teacher telling you or the university tells you that this is important – but where is it important and why and all such kinds of questions.“*

Along the same line, the problem-solving approach seems to be emphasized, but in different ways. In SCE, the use of technical engineering knowledge is emphasized to solve real problems, whereas the UPM staff stresses that students apply the perspectives and knowledge of others in defining and solving complex problems. And likewise, creativity and innovation are stressed by SCE as the ability to combine old ideas with new ideas, whereas the UPM staff stresses the ability to think out of the box.

Thereby, two problem-solving strategies seem to come forward, a technical-procedural strategy and a more interdisciplinary-collaborative strategy, both within the frame of a PBL environment. Not surprisingly, reading through the curricula, the Structure and Civil Engineering program is more technical and the Urban Planning program seems almost to supplement this technical view by its interdisciplinary and social perspective. Again, getting students together and making them work across programs seems like a natural choice. However, the distinction between a procedural and a collaborative strategy is harder to explain, as these competences move across disciplinary borders, and, in this aspect, there seems to be potentials for self-reflection at the study board level as well as cross-fertilization between the two study boards.

*4. Different identities – working in or between disciplines.*
There is no doubt that the staff from Civil Engineering is very much aware of disciplinary borders. They find it difficult to expand these borders, although they might find it relevant to do so. One approach is to give sustainability a marginal role in the curriculum; another approach is to push ESD to the workplace, as one of the staff members from SCE proposed (Staff interview d, 2013):

*”But it's (ed.: ESD) something that is not done very much; I would say because it is not very relevant to the type of projects they have, so instead... they could do maybe… and here we focus on technical aspects and maybe we are more thinking that it is better that they learn the technical things here and these other things that they can maybe learn afterwards in real life. Because they could learn a lot about these things and they couldn't design a building that is not safe.”*

On the other hand, it is striking that the request for inter-disciplinarity, which is one of the fundamental PBL principles, is now so strong that disciplines in fact are identifying themselves as being anything else than disciplinary. This is the case of UPM, where the emphasis on being multi-/cross-/inter-/transdisciplinary seems more important than the knowledge presented in STEM courses or within the engineering subfield.

However, when looking into the written curricula of UPM, it is not explicitly stated that students are to enter into interdisciplinary groups. Therefore, the interdisciplinarity seems to be provided “second-hand” by lecturers/facilitators who are able to provide different perspectives and inputs. The students themselves might then develop a new kind of hybrid discipline, constructed from the different perspectives, but nevertheless, not necessarily more open to collaboration. However, the students who collaborate beyond UPM could represent another way of working inter-disciplinarily – and in fact, sustainability could be a theme which could foster this kind of collaboration between students in different programs.

## Conclusions

In this study, we have investigated in which way the Problem-Based Learning (PBL) environment is reflected in the ESD taking place in two engineering Master's programs - Structure & Civil Engineering (SCE), and Urban Planning & Management (UPM) at Aalborg University.

At the theoretical level, we have highlighted ESD knowledge, skills and competences based on a literature review and structured these around five themes: 1) Systemic and holistic thinking, 2) Flexibility and adaptability, 3) Contextual thinking, 4) Problem solving, 5) Participatory education and decision-making, and 6) creativity and innovation. Sustainability aspects are extracted in terms of the three pillars of sustainability: the economic, the environmental and the social, by use of the Global Reporting Initiative (GRI, 2011). Different types of knowledge (factual/conceptual, procedural, metacognitive and evolutionary) and different levels of disciplinarity (disciplinary, cross/multidisciplinary, interdisciplinary and trans-disciplinary) are defined according to learning theory. At the empirical level, we have used questionnaires designed as checklists presented in the context of face-to-face interviews to investigate the staff's perception of what engineering students do; which aspects they touch upon, and which type of knowledge they gain when addressing sustainability in a PBL environment.

The results show considerable differences in the way in which the two programs approach PBL as well as ESD. One of the programs has a strong disciplinary profile; whereas the other is in fact identified as being anything else that disciplinary. One program emphasizes the economic and environmental aspects of sustainability; whereas the other stresses the social aspect. One of the programs has what could be termed a technical-procedural problem-solving strategy; whereas the other takes a more interdisciplinary-collaborative point of departure.

The discussion has raised the following questions, which call for further reflections at the conceptual, political as well as practical levels:

- How can the students experience interdisciplinary learning themselves by working on projects across the borders defined by the programs – and how can sustainability work as a boundary object in this concern?
- How do the different programs select appropriate ESD curricula content, and which sustainability aspects move beyond disciplines?
- How can the curricula open up for integrating ESD without compromising traditional STEM competences?
- How do study boards make sure that the abstract thoughts of systemic and holistic competences are carried out in practice – and which level in the knowledge taxonomies should be reached?

The two programs, however, also had similarities, including a strong emphasis on problem solving and on systemic and holistic perspectives. This indicates that a PBL framework can make perfect room for integrating ESD, but the need for adaptation to the different disciplines at the same time calls for a coordinated and comprehensive ESD strategy to make use of the provided space.

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# Appendix 1 – Results of checklist A

| | | *Structure & Civil Engineering* | | | | | | | *Urban Planning and Management* | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **C.F.** | **R.J.** | **B.N.** | **J.A** | **J.S.** | **H.T.** | **J.N.** | **C.L.** | **S.L** | **D.G** | **E.L** | **K.O(*)** | **P.D** |
| | | *Study Board* | | | *Lecturers* | | *Supervisors* | | *Study board* | *Lecturers* | | *Supervisors* | | |
| **A.1.Systemic & holistic** | A.1.1. Capable of placing engineering field in perspective with others areas of knowledge | X | | | | | | | | | | | | |
| | A.1.2. Develop knowledge beyond core STEM disciplines like sociology, ethics, business, etc. | | | | | | | | X | | | | X | |
| | A.1.3. Aware that engineering practice influences, and is influenced by, other professional practices | **X** | | **X** | **X** | | | **X** | **X** | **X** | **X** | | | |
| **A.2.Flexibility and adaptability** | A.2.1. Handle uncertainty by keeping open as many future options possible | | X | | | X | | | | | | | X | |
| | A.2.2. Reflect on how alternative solutions that fit with the sustainable development approach can be identified | | | | X | | | | | | | X | | |
| | A.2.3. Accept that there are no guarantees that our solutions will be truly sustainable – we therefore must do our best with the skills, knowledge and resources we have at our disposal | | | | X | | | | | | | | X | X |
| **A.3.Contextual** | A.3.1. Develop alternative solutions that are locally relevant | X | | | X | | | X | | | X | | | X |
| | A.3.2. Develop alternative solutions that are culturally appropriate | | | | | | | | | | | | | |
| | A.3.3. Seek to minimize the negative, and maximizing the positive, impacts of engineering practices both locally and globally | | | | X | | | | | | | | | |
| **A.4.Problem Solvers** | A.4.1. Use technical engineering knowledge to solve real problems | **X** | **X** | **X** | **X** | **X** | **X** | **X** | | | X | | | X |
| | A.4.2. Involve others' perspectives and knowledge (e.g. local representatives, politicians, stakeholders, etc.) in defining and solving complex problems | | | | | | | | **X** | | | **X** | **X** | **X** |
| | A.4.3. Retain the sustainability focus on the intended outcome right through the assessment and/ or implementation of the solution | | | | X | | | | | | | | | |
| **A.5.Participatory & decision maker** | A.5.1. Bring social, economic and environmental experts and implications to seek a balanced decision | | | | | | | | X | | | X | | |
| | A.5.2. Professional engineers participate in the decision making as well as in their professional roles | X | | X | X | | | | | | | | | |
| | A.5.3. Participate actively in the discussion and definition of social and economic policies to redirect society to a more sustainable development. | | | | | | | | **X** | **X** | | | **X** | |
| **A.6.Creativity and innovation** | A.6.1. Divergent thinking among peers | | X | | | | | | | X | | | | |
| | A.6.2. Thinking "out-of-the box" | | | X | | | X | X | | **X** | | **X** | | **X** |
| | A.6.3. Combining old ideas with new ideas | | **X** | **X** | **X** | **X** | | **X** | | | | | | |
| | A.6.4. Create new ideas with others | | X | | | | | | | | | X | | |

(*)Added a suggestion: learn to think reflectively and critically (navigate complexity)

## Appendix 2 – Results of checklist B

| | | Structure & Civil Engineering | | | | | | | Urban Planning and Management | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | C.F. | R.J. | B.N. | J.A | J.S. | H.T. | J.N. | C.L. | S.L(*) | D.G | E.L | K.O | P.D |
| | | Study Board | | Lecturers | | | Supervisors | | Study board | Lecturers | Supervisors | | | |
| B.1.Environmental | B.1.1.Materials (e.g. conservation of the global resource base and efforts to reduce the material intensity and increase the efficiency of the economy; ability to use recycled input materials; conservation of the global resource base; recycled materials and the overall costs of operations.) | X | X | | X | X | X | X | X | | | X | | |
| | B.1.2.Energy (renewable, efficiency, consumption, etc.) | | X | | | X | X | X | | | | | | |
| | B.1.3.Water (e.g. consumption, efficiency, etc.) | | | | | | | | | | | | | |
| | B.1.4.Biodiversity (e.g. impacts on, recovering, etc.) | | | X | | | | | | | | | X | |
| | B.1.5.Emissions, effluents and waste (e.g. reduction, management) | | X | | | | | | | | | | | X |
| | B.1.6.Products and services (e.g. life cycle assessment, impact of, initiatives for mitigation, transportation etc.) | X | X | X | X | | | | | | | | | |
| B.2.Social | B.2.1.Human rights (e.g. child labor, forced and compulsory labor, discriminatory | | | | | | | | X | | | | X | |
| | B.2.2.Labor practices and decent work (employment, labor/ management relations, training and education, diversity & equal opportunity, etc.) | | | | | | | | | | | | | |
| | B.2.3.Local government | | | | | | | | X | | X | X | X | X |
| | B.2.4.Public policy and legislation | | | X | X | | | | X | | X | X | X | X |
| | B.2.5.Local community engagement, impacts assessment and development programs | | | | | | | | X | | X | X | X | |
| | B.2.6.Product responsibility (e.g. public safety and health, marketing discourse, labeling and customer privacy) | X | | | X | | | X | | | | | | |
| B.3.Economic | B.3.1.Economic performance (e.g. direct economic impacts of the organization's activities and the economic value added by these activities on local communities) | X | | X | X | | | | | | | | | |
| | B.3.2.Market presence and interactions in specific markets (e.g. policy, practices, and proportion of spending on locally-based suppliers at significant locations of operation) | | | | | | | | | | | | | |
| | B.3.3.Indirect economic impacts (e.g. economic impacts created as a result of the organization's economic activities and transactions) | | | | | | | X | | | | | | |
| | B.3.4.Risk analysis (e.g. financial implications and other risks and opportunities for the organization's activities due to climate change) | X | X | X | X | X | X | X | | | | | | X |
| | B.3.5.Emerging economies in low-carbon economy and growth in developing country investment | | | | | | | | | | | X | | |

(*) Refused to fill in – see reasons in A~~a~~ppendix 6.

# Appendix 3 – Results from checklist C

| | | *Structure & Civil Engineering* | | | | | | | *Urban Planning and Management* | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **C.F.** | **R.J.** | **B.N.** | **J.A** | **J.S.** | **H.T.** | **J.N.** | **C.L.** | **S.L** | **D.G** | **E.L** | **K.O** | **P.D** |
| | | *Study Board* | | *Lecturers* | | | *Supervisors* | | *Study board* | *Lecturers* | *Supervisors* | | | |
| **C.1.Factual & conceptual (know-what)** | C.1.1. Knowledge about facts, elements and/ or terminology | | **X** | **X** | **X** | **X** | **X** | **X** | | | X | | | X |
| | C.1.2. Knowledge of principles and generalizations | | | | X | X | | | X | | | | | X |
| | C.1.3. Knowledge of theories, models and structures | **X** | **X** | **X** | **X** | **X** | **X** | **X** | **X** | **X** | **X** | | | **X** |
| **C.2.Procedural (know-how)** | C.2.1. Knowledge of subject-specific skills and algorithms | | | X | X | | X | X | | | | | | X |
| | C.2.2. Knowledge of subject-specific techniques and methods | **X** | **X** | **X** | **X** | **X** | **X** | **X** | | | | | | X |
| | C.2.3. Knowledge of criteria for determining when to use appropriate procedures (e.g. systematic assessment and readjustment of the solving methodology - methods, approaches to questions formulated, etc.) | **X** | **X** | | **X** | **X** | | | X | | | X | X | |
| **C.3.Metacognitive** | C.3.1. Strategic knowledge (combination of know what, know when and know how) (e.g. transfer and apply knowledge according to the situation - which methods, how to use, when to use, why it is use and related with the overall problem) | | X | X | X | | | | | X | | X | X | |
| | C.3.2. Knowledge about cognitive tasks, including appropriate contextual and conditional knowledge (combination of know-what, know-when, know-how) (e.g. go back and look if the solving process is aligned with the problem formulated) | X | | | X | | | | | X | | | X (?) | |
| | C.3.3. Awareness of the limits of one's knowledge (self-knowledge) | **X** | | **X (?)** | **X** | **X** | | **X** | **X** | | **X** | **X** | **X** | |
| **C.4.Evolutionary, or world** | C.4.1. Knowledge regarding the reasons behind the know-what, know-when, know-how and know-who | | | | X | | | | **X** | **X** | **X** | | **(X)** | |
| | C.4.2. Knowledge shared and cultured (relate with knowledge production) | | | | X | | | | | | | | | X |
| | C.4.3. Knowledge about others (actors, disciplines, communities, systems) values and attitudes (importance and challenges of others moral perspectives on issues) (e.g. other discipline members beliefs of what is right and wrong, values and behavior, etc.) | | | | X | | | | | **X** | **X** | **X** | **X** | |

# Appendix 4 – Results of checklist D

| | | *Structure & Civil Engineering* | | | | | | | *Urban Planning and Management* | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **C.F.** | **R.J.** | **B.N.** | **J.A** | **J.S.** | **H.T.** | **J.N.** | **C.L.** | **S.L** | **D.G** | **E.L** | **K.O** | **P.D** |
| | | *Study Board* | | | *Lecturers* | | *Supervisors* | | *Study board* | *Lecturers* | | *Supervisors* | | |
| **D.1.Disciplinary** | D.1.1. Knowledge within your engineering subfield | **X** | **X** | | **X** | **X** | **X** | **X** | | | | | | |
| | D.1.2. Study of courses related with engineering (e.g. mathematics, physics, etc.) | **X** | **X** | **X** | **X** | **X** | **X** | **X** | | | | X | | |
| **D.2.Multidisciplinary** | D.2.1. Have knowledge from different disciplines (e.g. history) | | | X | | | | | **X** | **X** | | | **X** | **X** |
| | D.2.2. Aware of others disciplines works | | **X** | | **X** | **X** | **X** | **X** | | X | X | | | X |
| | D.2.3. Study of others subjects like finance, humanities, etc. | | | | | | | | X | X | | | | |
| **D.3.Cross-Disciplinary** | D.3.1. Topic of investigation is from other area of study | | | | | | | | | | X | | X | X |
| | D.3.2. Use of techniques and tools that is commonly used by experts of other disciplines (e.g. using interview as method in civil engineering project) | | X | | X | X | | | | X | | X | X | |
| **D.4.Interdisciplinary** | D.4.1. Combines methods and approaches from different disciplines | **X** | | **X** | | | **X** | **X** | **X** | **X** | | | **X** | **X** |
| | D.4.2. Two or more disciplines which interact and combine their expertise to jointly address an area of common concern. | | | | | X (?) | | | **X** | **X** | **X** | **X** | | |
| **D.5.Transdisciplinary** | D.5.1. Formulate new theories and methodologies from different disciplines | X | | X (?) | | X (?) | | X | X | X (?) | | | | X |
| | D.5.2. Two disciplines merge to create a new one (e.g. nanotechnology, product design and technology…) | | X | | | | | | | | | | | |